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PHOTOCONDUCTIVITY - KSCIPCE

1. Key Concepts

- Semiconductors
- Einstein’s relations (Interaction between light and matter)
- Electronic band structure

2. Introduction

Semiconductors devices are ubiquitous in the science and technology sphere today. The study of basic physical properties (i.e, electrical, optical) of semiconductor materials and devices will aid us in developing more efficient and tailor made devices for the industry and research

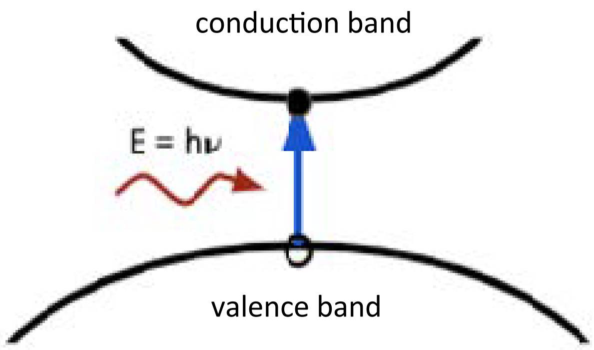
3. Objective

To study the photoconductivity of CdS, in the following conditions

- Applied voltage vs photocurrent (IPH) at constant irradiance (Φ).
- Photocurrent (IPH)vs irradiance (Φ) at constant applied voltage (V).

4. Theory

Optical properties of a semiconductors have contributions from electrons and lattice respectively. The study of electronic contribution to the optical properties of a semiconductor is more important because of its practical applications.



The Fundamental absorption process

An electron absorbs an incident photon and makes a transition from valance band to conduction band. The energy of the absorbed photon must be equal to or larger than the bang gap.
The frequency of the incident light should be $\nu_0 = \frac{E_g}{h}$

where ,
Eg: is the energy gap in the semiconductor
h: is the Planks’ constant
ν_0: The frequency is referred to as the absorption edge.

Photoconductivity

The phenomenon of photoconductivity occurs when an incident light shown upon a semiconductor causes an increase in its electrical conductivity. This is because of excitation of electrons across the energy gap into the conduction band, which leads to an increase in the number of free carriers in the conduction band, hence, an increase in the conductivity of the semiconductor.

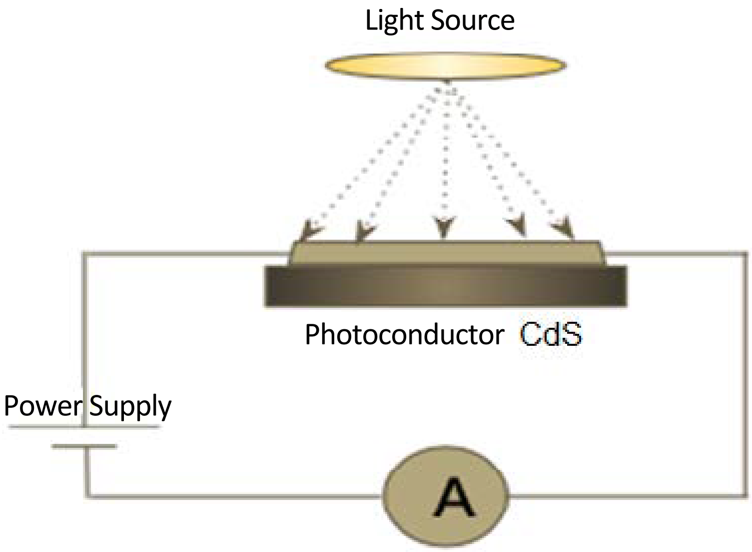


Image 2. Photo conductor

In a semiconductor, we know that there are two types of charge carries viz, the electrons and holes. The conductivity is a result of both the charge carriers.

$$\sigma = e\,(\mu_n n + \mu_p p)\ (1)$$

where σ: is conductivity, e: charge of an electron, μ_n: mobility of the electrons, n: concentration of electrons, μ_p: mobility of holes and p: concentration of holes.

The equation for conductivity in a semiconductor when there is no light incident on it is given by equation 2

$$\sigma_0 = e(\mu_e n_0 + \mu_h p_0)\quad (2)$$

Where, n_0 and p_0 are the concentration of electrons and holes respectively in equilibrium and σ_0 is the conductivity in dark.

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When the semiconductor is irradiated with light of frequency vo, there is an increase in the concentration of the free carriers in the semiconductor (Δn and Δp is the increase in the concentrations of electrons and holes respectively). Since, in semiconductors the electrons and holes are created in pairs, the number of electrons and holes produced will be the same. Δn=Δp.

The conductivity of the semiconductor under illumination is given by equation 3,

$$\sigma = \sigma 0 + e\Delta n\,(\mu e+\mu h) \quad (3)$$

The relative increase in the conductivity is given by equation 4,

$$\frac{\Delta\sigma}{\sigma_0} = \frac{e\Delta n\mu_h(1+b)}{\sigma_0} \qquad (4)$$

where, b=μe/μh is the mobility ratio.
The ratio Δσ/σ0 is greater than equal to one. The Semiconductor material has a higher value of conductivity.

For an intrinsic semiconductor of volume W×L×D, under constant illumination by radiation of energy $E=h\nu_0$. The total number of of photons impinging on the surface is $P_{OPT}/(h\nu_0)$. At the steady state, the rate of generation of charge carriers will be equal to the recombination rate. We know that the one of the factors that influence the conduction in an intrinsic semiconductor is the population of charge carriers in the conduction band. Under the steady state condition, the rate of generation of charge carriers is given by equation (5)

$$G=n/\tau=((\eta\times P\_OPT)/h\nu)/WLD \quad (5)$$

Where η is the quantum efficiency (the number of charge carriers generated per photon) and n is the carrier density. The photo current flowing generated is given by equation 6.

$$I\_p=(\sigma\times\varepsilon)WD=(q\nu\_n\ n\varepsilon)WD=(qnv\_d)WD \quad (6)$$

ε is the electric field inside the semiconductor and v_d is the drift velocity of the charge carriers. Substitution for n in (5) into (6) we get

$$I\_p=q\times\eta\ p\_OPT/h\nu\times(\mu\_n\ \tau\varepsilon)/L \qquad (7)$$

τ is the carrier lifetime.
From equation 7 it is evident that, for a given sample of semiconductor. The photocurrent is directly proportional to

1. The optical power of the incident radiation.
2. The value of the applied electric field.

5. Equipment

S.No	Equipment	Item Code	Qty
1	Optical Bench Set 0.4m	KSCIOB2	1
2	Light Source Holder	KSCIHA001	1
3	Polarizer Holder	KSCIHA004	1
4	Analyzer Holder	KSCIHA006	1
5	LDR Module Holder	KSCIHA020	1
6	Power Supply 0-15V, 200mA	KSCIPS61022D/20	1
7	Power Supply for Light Source	KSPS61022D/2	1
8	Complete Equipment Set With Instruction Manual	KSCIPCE	1

6. Safety instructions

- Components like horizontal bench and power supply are heavy. Take adequate safety measures while handling them.

7. Experimental Setup

- Place the optical bench on a stable horizontal surface such as a sturdy table top and make sure the bench is parallel to the horizontal surface using the adjustable mounts.
- Mount the light source securely on the upright, place the upright on the optical bench and lock the slide screw on the slider.
- Mount the polarizer stage on the upright, place it adjacent to the light source (along the optical path) and lock the slide screw on the slider.
- Mount the analyzer on the upright, place it adjacent to the polarizer and lock the slide screw on the slider.
- Mount the (LDR) photo resistor on the upright and place it adjacent to the analyzer. Connect it to the power supply 0-15V 200mA.
- Ensure that the light source, polarizer, analyzer and the LDR are all aligned in the same optical axis.

8. List of Experiments

- Power up (12 V DC) the light source and also switch on the power supply connected to the LDR
- Rotate the analyzer such that the angle between the polarizer and analyzer is $\theta=0°$.

8.1 Applied voltage vs photocurrent at constant luminous flux

- The luminous flux on the LDR is controlled by using polarizer analyzer combination.
- Keeping θ=0°, measure the photocurrent for different voltages applied to the LDR. Plot the graph of photocurrent vs applied voltage.
- Repeat the experiment for θ=30°, θ=60°, θ=90°

8.2 Luminous flux vs photocurrent at constant applied voltage

- Recalling from Malu's law, the ratio of light intensity at an angle θ to that at θ=0° is equal to cos^2 (θ). Therefore, we can get the relative light intensity (luminous flux) by measuring θ and calculating cos^2 (θ).
- Keeping the voltage applied to the LDR constant, vary θ in steps of 10° and measure the photocurrent for each trial. Plot the graph of photocurrent vs luminous flux (proportional to cos^2 (θ)).
- Repeat the experiment for different values of applied voltage.

9. Measurements

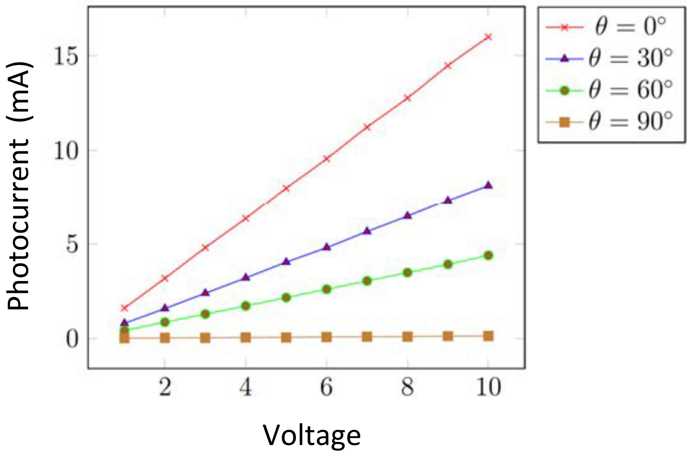
Table 1. Dependence of photocurrent on applied voltage at constant light flux

Voltage, V	Photocurrent IPH, mA at constant light flux			
	$\theta = 0^0$	$\theta = 30^0$	$\theta = 60^0$	$\theta = 90^0$
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

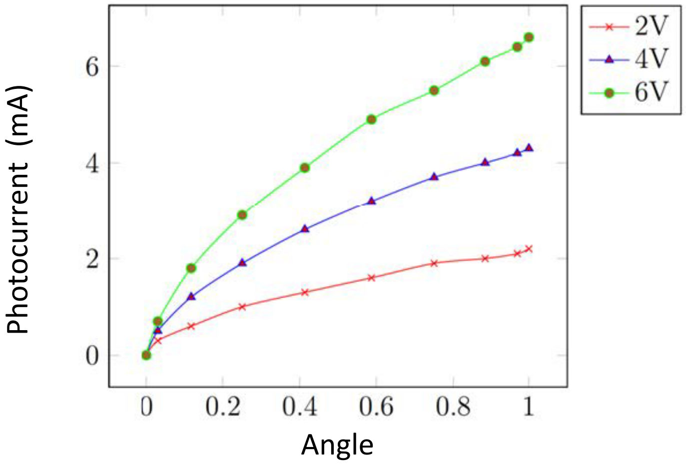
Table 2. Dependence of photocurrent on light flux at constant applied voltage

θ (°)	θ(radians)	$cos^2\theta$	Photocurrent IPh, mA at constant applied voltage		
			U = $2B$	U = $4B$	U = $6B$
0					
10					
20					
30					
40					
50					
60					
70					
80					
90					

Photocurrent vs Voltage



Photocurrent vs Analyzer Angle



10. Applications

As a consequence of having a high gain (1-to-10^6) and a large operating temperature window (4.2 K to 300 K). photo conductors have a wide range of applications.

High sensitivity far Infrared detectors: Extrinsic semiconductors are used photo detectors to detect long wavelengths. To minimize thermal noise the semiconductors must be cooled.

Radiometry: Photoconductors can be used for measuring properties like optical power, luminous flux, optical intensity and irradiance

Photo conductors that have a small response time are used in optical fiber communications, optical frequency metrology and in the characterization of pulsed lasers.

Two-dimensional arrays containing many identical photo detectors are used as image sensors for imaging applications.

11. Reference

- Physics of semiconductor devices, S.M Sze, Wiley publication
- Microelectronics: An Integrated Approach, Roger T. Howe and Charles G. Sodini, Prentice Hall